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Root Diseases in Oregon and Washington Conifers

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Preface

Root diseases are responsible for large losses of timber in Pacific Northwest forests. All conifer species and all forested areas suffer damages from root diseases. This booklet has been prepared for foresters and others concerned with controlling conifer root diseases in Oregon and Washington forests. It describes how to recognize the most important root diseases, how they spread and damage host tress, and how to reduce losses. Resource productivity of infested sites can be significantly expanded by controlling root diseases.

The information presented has been compiled from many sources and represents more than 75 years of research and observations by forest pathologists in the Pacific Northwest.

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Introduction

Much is known about conifer root diseases in the Pacific Northwest. The information is scattered in many publications and some has never been published; there are numerous contradictory statements and opinions. In this booklet, we have tried to bring together information on root diseases that would be useful to foresters. We hope this publication will take much of the mystery out of tree root diseases and inform you of practices that will reduce the losses they cause.

This booklet is about fungus-caused root diseases of conifers in forest settings. Root diseases can be caused by abiotic agents such as flooding, soil compaction, drought, and toxic compounds, but most really damaging root diseases are caused by fungi.

Five root diseases are responsible for most of the damage in Oregon and Washington: laminated root rot, Armillaria root disease, annosus root disease, black stain root disease, and Port-Orford-cedar root disease. Less common root diseases can be important locally, but will cause only minor losses regionally: these are Schweinitzii root rot, tomentosus root rot, and yellow root rot. Each root disease is described in subsequent sections of this booklet.

Ten years ago, forest pathologists and a few foresters were the only ones interested in tree root diseases. Now, root diseases are widely recognized by foresters as the most serious and difficult of all diseases to control. Root diseases are thought to be associated with at least 18 percent of the annual conifer mortality volume in the western United States. All tree species are affected by one or more root-destroying fungi—no tree species is immune to infection, and no forested area of Oregon or Washington is without root disease. All forest resources can be affected, either directly or indirectly, by root diseases.

Root disease identification and management are emphasized in this booklet. A key step to reducing losses from root diseases is to recognize the diseases. Failure to detect them will result in continued losses and usually increased losses. It is important to be able to recognize the specific root diseases affecting trees because treatments differ depending on the causal fungi and hosts. Root diseases can be difficult for inexperienced observers to recognize. Trees affected by root diseases frequently are assumed to have been killed by other causes, particularly insects, because the root disease fungi are not easily seen.

Root diseases can be detected by symptoms in tree crowns, but the specific root disease generally cannot be identified by looking only at above-ground portions of trees. Accurate identification usually requires digging to expose roots for examination. Root disease-affected trees typically go through a sequence of symptoms. Reduced height growth, seen as rounding of tops, is evident first and is followed by a loss of needles (which results in thin crowns); yellowing of foliage; dying of branches; production of smaller-than-normal distressed cones; and finally death.

Root diseases typically affect neighboring trees. In these situations, root disease can be identified as the most probable cause of damage if symptoms on adjacent trees range from reduced height increment and sparse foliage to snags that have been dead for several years. This range of symptoms results from slow spread and long-term persistence of fungi in tree roots. Root diseases cause a slowly spreading progression of death in affected stands. On the other hand, if most or all of the dead and dying trees in a cluster are in the same stage of deterioration, the cause of death is unlikely to be root disease. Table 1 lists symptoms and signs associated with the most common root disease fungi.

The long-term persistence of root disease fungi on a site is a big obstacle to control. This persistence may range from 1 or 2 years to hundreds of years. Host size and stocking density, as well as fungus species, influence fungus survival. Woody tree roots and stumps provide fungi with good protection from destructive forces. Root disease fungi persist on a site in two basic ways -- slow spread and ability to live in dead wood. The fungi that cause black stain root disease and Port-Orford-cedar root disease do not survive long in dead roots or soil; they persist on sites by spreading to and infecting adjacent trees. If they kill all host trees on a site, these two fungi soon die. Other root disease fungi that decay woody portions of roots also persist on sites by slow spread and an ability to survive for long periods in large dead roots and stumps. They do this by enveloping themselves in protective sheaths of hyphae or resin produced by the trees. Because of this long-term survival of fungi, growth of susceptible conifers on sites affected by root diseases may be greatly reduced for decades unless control efforts are carried out.

With the exception of black stain root disease, which kills trees by plugging water-conducting tissues, root disease fungi injure trees by decaying and killing roots. Damage caused by root diseases is expressed by reduced rate of growth, cull through butt rot and stain, windthrow, death, and predisposition to attack by other disease-causing organisms and insects. Trees affected by root diseases are attractive to many insects that may infest them and hasten their death. Insects can increase their populations in root-diseased trees and then attack nearby healthy trees.

Infection processes vary among root disease fungi and are described in subsequent sections. All root disease fungi are capable of spreading within roots by mycelial growth and from tree to tree through root contacts.

Susceptibility to infection and to associated damage by the five major root diseases varies with tree species. Susceptibility is defined as the likelihood of a tree species becoming damaged if it contacts inoculum of the root disease fungus. Infection/damage susceptibility is rated on a four-step scale (Table 2). These ratings are based on observations of damage in Oregon and Washington, not upon comparative inoculations. Ratings could be different for the same pathogen-host combinations in other areas of western North America.

Is the incidence of forest root diseases increasing? We do not have data for all root diseases, but we know that some are causing more damage now than in the past. Without a doubt, losses caused by annosus root disease, black stain root disease, and Port-Orford-cedar root disease have increased in direct response to human activities in the forests. Actions that cause accelerated losses are discussed in the subsequent sections.

We hope the most valuable message in this publication is that management strategies are available for preventing and reducing forest resource losses caused by root diseases. Management of root diseases offers opportunities for large increases in forest productivity. Root disease losses can be reduced by manipulating tree species during thinning and reforestation, by thinning to improve vigor, by reducing or eliminating inoculum; by excluding the pathogens from susceptible hosts, and by applying pesticides.

The scientific names of several root disease fungi have been changed in the last 10 years as a result of taxonomic research. All the root diseases have more than one common name, and this can obviously cause confusion. We are using the names that are in current usage in the Pacific Northwest. Table 3 can be used as a cross-reference for names.

Table 1. – Symptoms and signs of five important forest root diseases in the Pacific Northwest.

Symptoms and Signs	Laminated root rot	Armillaria root disease	Annosus root disease	Black stain root disease	Port-Orford-cedar root disease
Reduced height growth	X	X	X	X	
Yellow foliage	X	X	X	X	X
Slow loss of foliage	X	X	X	X	
Distress cones	X	X	X	X	
Slow crown decline	X	X	X	X	
Rapid tree death		X		X	X
Dead tree, no foliage loss		X			X
Abundant basal resin flow		X			
Cinnamon stain in inner bark					X
Black stain in sapwood				X	
Roots rotted	X		X		
Windthrown live trees	X		X		
Insect galleries under bark	X	X	X	X	X
Fleshy yellow-golden mushrooms on tree base		X			
Mycelial fans		X			
Rhizomorphs		X			
Leathery conks			X		
Setal hyphae	X				
Ectotrophic mycelium	X				
Creamy leathery pustules on roots			X		
Advanced decay:					
Laminated decay with pits on both sides of sheets	X				
Laminated decay with pits on only one side of sheets			X		
Yellow, stringy decay with black zone lines		X			
White, stringy decay with black specks			X		

Table 2. – Relative susceptibility of conifers in Oregon and Washington to damage by five common root diseases.

Hosts	Laminated root rot	Armillaria root disease	Annosus root disease	Black stain root disease	Port-Orford-cedar root disease
West Side Douglas-fir	1*	2**	3	1	4
East Side Douglas-fir	1	1	3	3	4
Ponderosa pine	3	2	2	3	4
Lodgepole pine	3	2	2	3	4
Western white pine	3	2	3	4	4
Sugar pine	3	2	3	4	4
Grand fir	1	1	1	4	4
White fir	1	1	1	4	4
Pacific silver fir	2	2	1	4	4
Noble fir	2	2	2	4	4
Subalpine fir	2	2	2	4	4
California red fir	2	2	2	4	4
Western hemlock	2	2	2***	3	4
Mountain hemlock	1	2	1	3	4
Larch	2	3	3	4	4
Engelmann spruce	2	2	3	4	4
Sitka spruce	3	2	3	4	4
Western redcedar	4****	2	3	4	4
Incense cedar	4	3	3	4	4
Port-Orford-cedar	4	3	3	4	1

*1 = severely damaged,
2 = moderately damaged,
3 = seldom damaged, and
4 = not damaged.

**West Side Douglas-fir is moderately damaged up to age 25, susceptibility then decreases.

***Western hemlock is not severely damaged until it exceeds 150 years.

****Western redcedar east of the Cascade Range may have butt rot caused by laminated root rot.

Table 3. – Scientific and common names of root disease fungi and associated diseases found in the Pacific Northwest, by order of common usage.

SCIENTIFIC NAME	**COMMON NAME**
Phellinus weirii = *Poria weirii*	Laminated root rot, yellow laminated rot, *Phellinus weirii* root rot, yellow ring rot, paper rot, poria root rot
*Armillaria obscura**, *Armillaria mellea* = *Armillariella mellea*	Armillaria root disease, shoestring root rot, mushroom root rot, crown rot, rhizomorphic root rot, toadstool disease, spongy root and butt rot, oak fungus, honey mushroom
Fomes annosus = *Fomitopsis annosa* = *Heterobasidion annosum*	Annosus root disease, Fomes root and butt rot, white spongy rot, spongy saprot, white pocket rot, white stringy rot
Ceratocystis wageneri = *Verticicladiella wagenerii*	Black stain root disease, Verticicladiella root disease
Phytophthora lateralis	Port-Orford-cedar root disease, phytophthora root rot of Port-Orford-cedar
Phaeolus schweinitzii = *Polyporus schweinitzii*	Schweinitzii butt rot, brown cubical butt rot, red-brown butt rot, velvet-top fungus, cow-pie fungus
Inonotus tomentosus = *Polyporus tomentosus, Polyporus circinatus*	Tomentosus root rot, white pocket root and butt rot, stand opening diseases, red-brown root and butt rot
Perenniporia subacida = *Poria subacida*	Yellow root rot, white root conk, feather rot, spongy root rot, stringy butt rot

*Recently published research has determined that the species of Armillaria pathogenic to Pacific Northwest conifers is *Armillaria obscura*. *Armillaria mellea* is not known to occur in western North America.

Key to Major Conifer Root Diseases in Oregon and Washington and Agents Frequently Confused With Them

1. (a) Single, isolated dead tree or groups of trees all dying at the same time (fig. 1); in young stands (less than 20 years old), mortality not associated with stumps of the former stand 2
   (b) Groups of trees dying over many years; declining trees intermixed with and/or surrounding trees that have died in previous years (figs. 2 and 3); symptoms of decline include foliage yellowing, growth deceleration, crown thinning, and/or production of distress cone crops (figs. 4 and 5); in young stands (less than 20 years old), tree killing often closely associated with stumps of the former stand (fig. 6) 5
2. (a) Dead trees standing 3
   (b) Dead trees on the ground; most trees oriented in the same direction (fig. 7) with root systems usually intact; many species involved; frequently associated with shallow soils, seepage areas, or edges of recently created openings . . . . Windthrow*
3. (a) Port-Orford-cedar is the tree species affected; cinnamon-colored stain in inner bark of roots and butt (fig. 8) . . . . Port-Orford-cedar root disease
   (b) Douglas-fir, pine, or hemlock affected; distinct dark brown to purple-black stain confined to areas in the outer sapwood of roots and butts (fig. 9) . . . Black stain root disease
   (c) Dead trees with large sections of bark removed; obvious girdling, tooth or claw marks on exposed sapwood (fig. 10) . . . . Mammal damage
   (d) Dead trees with only small holes 1/4-inch in diameter or smaller in bark 4
4. (a) Dead trees with series of small holes in rows circling the bole, usually in one distinct zone (fig. 11) . . . . Sapsucker damage
   (b) Dead trees with pitch tubes, boring dust, and small, widely distributed entrance and exit holes in bark of stem; obvious insect galleries and associated stain under bark (fig. 12); roots not decayed or stained . . . . Bark beetle infestation*
5. (a) Roots not decayed; fungus structures absent; trees always die standing 6
   (b) Roots decayed; fungus structures may be present; trees frequently die standing but centers of infection also contain windthrown trees 7
6. (a) Port-Orford-cedar the tree species affected; cinnamon-colored stain in inner bark and sapwood of roots and butt; rootlets killed, but major roots not decayed . . . . Port-Orford-cedar root disease
   (b) Douglas-fir, pine, or hemlock affected; distinct dark-brown to purple-black stain confined to the outer area in sapwood of roots and butts . . . . Black stain root disease
7. (a) Decay laminated 8
   (b) Decay stringy or spongy 9
8. (a) Advanced decay always laminated, sheets readily separating at growth rings and frequently with round to oval pits on both sides (fig. 13); reddish, whiskery setal hyphae (fig. 14) between layers of decayed wood; reddish stain ahead of advanced decay in roots and butt on stumps, stain appears as crescents in early stages but later appears as a near or complete circle of chocolate brown stain at edge of the heartwood (fig. 15); persistent, white to gray crusty fungus sheath (ectotrophic mycelium) covering surface of root bark (fig. 16); trees with green crowns frequently windthrown with root systems rotted off to form "root balls" (fig. 17) in infection centers . . . . Laminated root rot
   (b) Advanced decay, occasionally laminated, but pitted on only one side if at all (fig. 18); lacking setal hyphae; brown to reddish stain with irregular margins in roots ahead of advanced decay (fig. 19); small leathery fruiting bodies with brown to buff tops and white pore layer sometimes found within stem or stump hollows, in root crotches, or growing out of bark just below the duff surface (figs. 20 and 21): small, cream-colored pustules occasionally found on roots (fig. 22); ectotrophic mycelium may be present but, if so, is sparse and thin; microscopic fruiting bodies readily produced in culture or on incubated sections of infected wood (fig. 23); windthrow in infection centers usually occurs after trees are dead . . . . Annosus root disease
9. (a) Live, infected trees frequently exhibit copious basal resin flow (fig. 24) or brown leachate (fig. 25); decay is a yellow stringy or spongy rot containing many black zone lines (fig. 26); small trees may not have obvious decay in roots. A yellowish-brown to red stain with a watersoaked appearance may be observed ahead of advanced decay (fig. 27); white or yellowish-white mycelial sheets resembling layers of latex paint and frequently fan-shaped are formed under bark of roots or butt (fig. 28); black, shoe string-like cords (rhizomorphs) may be present under the bark or on root surfaces (fig. 29): honey-colored mushrooms often are produced around the bases of infected trees and stumps in autumn (fig. 30) . . . . Armillaria root disease
   (b) Basal resin flow uncommon; white spongy or stringy decay, frequently with scattered black specks (fig. 31); fruiting bodies, stain, and ectotrophic mycelium as described in 8b . . . . Annosus root disease

*Note: Though wind and bark beetles cause tree mortality by themselves, they also frequently affect trees that have been weakened by root diseases. Carefully check trees that key out here for root diseases.

Laminated Root Rot

Laminated root rot, caused by the fungus, *Phellinus weirii,* is the most damaging root disease in the Pacific Northwest and one of the most difficult to control. It is estimated to cause annual losses of 32 million cubic feet of wood in western Oregon and Washington and may cause equally staggering losses in the eastern portions of both States. The disease is distributed throughout the two States except for a small area in southeastern Oregon (south of the Crooked River and east of Highway 97).

Hosts

P. weirii can infect all conifer species; however, some tolerate the pathogen better than others. Douglas-fir, mountain hemlock, white fir, and grand fir are highly susceptible (readily infected and killed); western hemlock, western larch, Pacific silver fir, subalpine fir, noble fir, California red fir, and the spruces are intermediately susceptible (often infected but rarely killed); and the pines and cedars are considered to be tolerant or resistant (seldom infected and almost never killed). All hardwoods are immune.

Recognition

Crown symptoms of trees affected by laminated root rot include retarded leader growth, short, sparse, and chlorotic faded foliage, and distress cone crops. Crown symptoms usually are not seen until at least half of the host root system is affected. Laminated root rot is distinguished from other root diseases that cause similar crown symptoms by the characteristic decay of roots and butts. The decayed wood separates readily at the annual rings with pits on both sides of the sheets. Reddish-brown, whiskery setal hyphae occur between the layers of decayed wood. A grayish-white, crusty mycelial sheath (ectotrophic mycelia) is found on root surfaces of young trees and within root bark crevices on old trees.

Fruiting bodies of *P. weirri* are appressed, brown, crusty structures with numerous pores that form on the lower sides of down trees or on exposed roots close to the ground. They are of little diagnostic value because they are inconspicuous and rather uncommon. Only about half the infected trees in a disease center will have crown symptoms. Approximately 75 percent of the infected trees can be detected by looking for stain or decay in fresh stump cross sections.

Damage

P. weirii extensively decays roots of highly susceptible host trees and either causes windthrow or kills them by destroying their ability to take up water and nutrients. Infected saplings and small poles usually die standing; larger trees are more likely to be windthrown. Infected trees may suffer growth loss for several years prior to death. *P. weirii* often predisposes highly susceptible hosts to bark beetle attack. Some highly susceptible trees that become infected survive for many years by confining the fungus to a small number of roots and the interior of butts where it can cause extensive decay. These trees are most frequently found in old-growth stands. Intermediately susceptible hosts generally suffer butt decay rather than extensive root destruction and mortality.

Disease Spread

P. weirii spreads little, if at all, by windblown spores. Virtually all spread is by mycelia on or within roots. The fungus does not grow through soil. The fungus persists from tree generation to generation in infested areas and can therefore be considered a disease of the site. It can survive up to 50 years in large roots and stumps of dead or cut trees and infect trees that become established nearby by growing across root contacts. Disease-induced resin impregnation of wood surrounding infections and the ability of *P. weirii* to form a protective hyphal sheath around itself are responsible for the pathogen's long-term survival.

When a site with stumps or snags infested by *P. weirii* is regenerated with susceptible tree species, it usually takes 10 to 15 years before root contacts between the new trees and the stumps or snags develop and mortality becomes obvious in the new stand. Laminated root rot has, however, been known to kill trees as young as 4 years. At first, killing involves scattered individuals close to the old stumps or seedlings planted directly on infected roots, but by the time the stand is 15 to 20 years old, *P. weirii* may be spreading from the original infection foci and forming expanding disease centers. Average rate of radial enlargement is about 1 foot per year.

Centers of laminated root rot eventually appear in the stand as variable-sized, understocked openings that contain dead standing trees, stubs, windthrows, and some unaffected trees.

Symptomatic trees in various stages of decline occur around the margins of centers. As susceptible trees die, centers commonly fill in with hardwoods, shrubs, resistant conifers, and sometimes regeneration of highly susceptible conifers. Susceptible trees frequently develop root contacts with viable inoculum and become infected. Many susceptible trees within 50 feet of the apparent edge of a disease center have a high probability of being infected even though they do not show crown symptoms.

There is no published evidence to indicate that laminated root rot is influenced by topography, climate, or soil conditions in Oregon and Washington. *P. weirii* occurs and causes severe damage on a variety of site types and appears to be well adapted to the same environmental conditions that favor susceptible hosts.

Management

Control of laminated root rot is best attained at the time of final harvest. Recommended control for the disease is to cut all hosts in infection centers along with a 50-foot buffer around each and either (1) replant the site with a less suceptible tree species or (2) treat inoculum.

The less susceptible tree species alternative involves planting or regenerating in disease centers immune, resistant, tolerant, or intermediately susceptible tree species that are adapted to the site. If immune, resistant, or tolerant species are grown for a rotation (50 years or more) on a *P. weirii*-infested site and susceptible species ingrowth can be prevented, the fungus will die out over most, if not all, of the area. Subsequent rotations of susceptible species can then be grown with little probability of significant reinfection. If intermediately susceptible tree species are planted on a diseased site, many will become infected and *P. weirii* inoculum will be maintained on the site, but in amounts less than if highly susceptible species had been grown.

The second option involves removing as many infected roots and stumps as possible or killing the pathogen within them with fumigants. Such treatments are biologically effective if done conscientiously but tend to be expensive. Stump removal has limitations, especially on steep slopes, and may cause substantial soil damage if done improperly. Fumigation is still in an experimental stage but shows promise.

When laminated root rot is encountered in sapling stands of highly susceptible tree species, the location and extent of the disease should be determined by surveys. Most infection centers should be visible in 15-year-old stands; however, the number of symptomatic trees in each center probably will be small. If the disease is not evident on more than about 25 percent of the area, thinning of diseased trees would be an appropriate treatment. In affected sapling stands, cut all trees with any symptoms of laminated root rot and cut adjacent nonsymptomatic host trees (the highly and intermediately susceptible species). Roots from such trees can serve as disease pathways from the infected trees to healthy trees. Tolerant, resistant, and immune tree species would not have to be cut if they were next to affected trees. Stocking density will influence the number of nonsymptomatic trees that have to be cut to break the disease pathway to healthy trees. In most sapling stands, the nonsymptomatic trees to be cut will be within a zone that extends two normal tree spacings beyond trees that have sparse, yellow foliage. The purpose of the treatment is to disrupt movement of *P. weirii* mycelium along root systems by killing the roots of the nonsymptomatic pathway trees. The fungus does not spread on dead roots.

This treatment will be effective only if tree markers or thinners are skilled in detecting symptoms of laminated root rot and can locate the periphery of disease centers. It is likely the treatment will not always stop the spread of laminated root rot in sapling stands. If the thinning is done by people trained in disease recognition, spread should be greatly reduced. Stand openings created by this treatment should be reforested with less-susceptible tree species. Always try to save less-susceptible tree species when precommercially thinning near disease centers.

If removal of all symptomatic trees and nonsymptomatic pathway trees were to create a stand of unacceptable stocking, consideration should be given either to destroying the stand immediately and reforesting the site with less susceptible tree species or to removing inoculum and planting with any tree species.

Silvicultural treatments, such as control of competing vegetation, precommercial thinning, and fertilization, intended to maximize growth rates of saplings will not make trees exposed to large amounts of inoculum more resistant to infection by *P. weirii*. On the other hand, there is no evidence these treatments increase spread of the disease. It would be appropriate to integrate these growth-stimulating treatments with the removal of symptomatic and adjacent nonsymptomatic trees as described above. This approach would enable the trees to reach harvestable size in the shortest time. If disease losses are unacceptable at that time, the stand could be harvested and the site reforested with a less susceptible tree species, or the stumps and roots could be treated and the site planted with any tree species.

It is not a desirable management alternative to do nothing in severely infested stands of saplings on average to good sites. The stand should be regenerated or growth-stimulating treatments should be applied to shorten the time needed for the trees to obtain harvestable size.

In pole-sized stands of highly susceptible species with numerous, evenly distributed centers of laminated root rot (20 percent or more of the area visibly affected), commercial thinnings should not be done. If access allows, however, merchantable-sized infected trees should be removed in periodic salvage operations. Disease progress should be closely watched, and strong consideration should be given to final harvest at a rotation age that is younger than usual. Following harvest, disease centers should be treated by manipulation of tree species or stump treatment.

In stands of pole-sized trees, where disease centers are not numerous or widely distributed, infected trees and trees likely to become infected before the next scheduled entry should be harvested during a commercial thinning entry. When determining which susceptible trees are likely to become infected in a specific time period, consider that nonsymptomatic susceptible hosts within 20 feet of symptomatic trees are likely to be infected and that disease centers expand radially at an average annual rate of 1 foot. Locations of laminated root rot centers should be recorded and, after final harvest of the stand, they should be treated by manipulation of tree species or stump treatment.

Windthrow of live, infected merchantable-sized trees can be beneficial because the volume of inoculum in the soil will be reduced as roots are pulled out. *P. weirii* will die in roots exposed to air. Seldom would all infected trees in a disease center be windthrown, so disease control will almost always be incomplete.

Where it is possible to salvage small volumes of windthrown, root-rotted trees yearly, thinning of diseased stands can produce some disease control. Remove symptomatic trees and host trees within one normal tree spacing and thin the rest of the stand to desired stocking levels. The probability of windthrow of live, infected trees cannot be accurately predicted, but most will occur in the first 5 years after thinning. The thinned, infested portions of stands should be examined yearly for about 5 years after thinning to determine windthrown and standing dead trees for salvage. It is important to salvage windthrown trees yearly to prevent outbreaks of bark beetles, especially Douglas-fir beetle, *(Dendroctonus pseudotsugae)* from developing in them.

Laminated root rot can pose a serious hazard in developed recreation areas. This disease should always be watched for during hazard rating inspections, and affected trees should be treated as soon as possible. Disease surveys in stands where construction of recreation sites is contemplated should be one of the very first activities undertaken. If laminated root rot is found, there should be no development.

Additional Reading

Laminated Root Rot

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Armillaria Root Disease of Conifers

Armillaria root disease of conifers is caused by the fungus, *Armillaria obscura*. It formerly was attributed to *A. mellea*, but recently the taxonomy of the genus *Armillaria* has been restructured. Armillaria root disease is the most common and most widely distributed forest root disease in Oregon and Washington. The disease is often found affecting trees that have been weakened by other agents, but large epidemics caused by Armillaria root disease alone have been detected in mixed-fir and pine forests east of the Cascade Range.

Recognition

Symptoms of Armillaria root disease include thin and/or chlorotic foliage; distress cone crops; abundant resin flow, or leaching of brown liquid at tree bases; a yellow-stringy root and butt rot, especially in nonresinous conifers such as hemlock and tree mortality, often centered around large stumps. Crown and root collar symptoms occur on only 15 to 20 percent of the living infected trees within disease centers; infection in the remaining trees is virtually undetectable.

Identification of Armillaria root disease is best done by looking for mycelial fans underneath the bark of roots and root collars of symptomatic trees. Mycelial fans are white mats of fungus that can be peeled off like latex paint. As trees die and deteriorate, mycelial fans fade from white to a yellow color and eventually disintegrate. Impressions of mycelial fans in the bark can be seen on trees that have been dead for several years.

Additional symptoms that distinguish Armillaria root disease from other major root diseases are presence of abundant basal resin flow, yellow-stringy decay, and honey-colored mushrooms that are sometimes produced in autumn on dead trees or stumps. *A.obscura* also often produces black shoestring-like structures called rhizomorphs that can be found in the soil around infected roots and under bark at the root collar of dead trees. Rhizomorphs are rootlike in form and are up to 1 to 2 mm in diameter; unlike roots, they have a white, nonwoody core.

Because *A.obscura* is present in most conifer stands as a saprophyte, it is often found in trees killed by other causes. Care must be taken to thoroughly examine tree roots and root collars for other pathogens, especially if resinosis is not prominent.

Hosts

All conifers in Oregon and Washington can be damaged by Armillaria root disease, but there are differences in degree of susceptibility and damage expression. In forests west of the crest of the Cascade Range, tree killing by Armillaria root disease is frequently associated with conditions that stress trees.

Armillaria root disease is especially likely to occur in Douglas-fir and noble fir plantations where low quality or offsite stock was planted or seedlings were poorly planted. Mortality caused by Armillaria root disease is most common in Douglas-fir plantations between the ages of 10 and 25. Tree killing after age 25 is uncommon unless the trees are stressed.

In forests east of the Cascade Range crest, damage caused by Armillaria root disease starts to become apparent at age 5 and may continue throughout the life of the stand. Habitat type has been found to influence the presence of Armillaria root disease in northern Idaho and eastern Oregon and eastern Washington. The fungus was nearly always present in plots established in cool and moist to warm and moist habitat types and was always absent in cold and dry, hot and dry, and frost pocket habitat types. Armillaria root disease was less likely to be found on high productivity sites characterized by having grand fir, western redcedar, and western hemlock climax series than on low productivity sites with subalpine fir and Douglas-fir climax series. Douglas-fir, grand fir, and subalpine fir showed the highest levels of infection when they were the climax species. The probability of finding pathogenic Armillaria on the high productivity habitat types was higher on plots that had man-caused disturbance than on undisturbed plots.

Disease Spread

Mycelium of *A.obscura* can survive as long as 35 years in old-growth stumps and roots before being replaced by other fungi and microorganisms. Duration of fungus survival is influenced by tree size, tree species, and possibly by habitat type. Large stumps and roots infected prior to harvesting provide more inoculum potential (energy available for infection of a host) than do small stumps because the former provide more food for the fungus. Stumps of precommercial size are not effective inoculum sources.

Spread of the pathogen from infected stumps or trees to adjacent healthy trees occurs mainly by mycelium growing across root contacts and, to a much lesser extent, by rhizomorphs. Rhizomorphs form after a stump or large root system has been colonized. They are capable of growing several feet through soil and can cause infection if they contact susceptible roots. Rhizomorphs do not have as much inoculum potential as mycelium growing in roots. Once a root is infected, the fungus can spread distally and proximally within it. Some trees, upon infection, will successfully occlude the fungus, resulting in little or no decay and growth reduction.

Damage

Tree killing is the most common form of damage caused by Armillaria root disease. Affected trees can be windthrown, but tend to die standing. Various species of bark beetles, particularly fir engravers *(Scolytus ventralis)* in white fir and grand fir,

will attack trees weakened by Armillaria root disease and may hasten tree mortality. Tree killing by Armillaria root disease will often increase 1 to 2 years after severe droughts or nearly complete defoliation by insects. *A. obscura* is able to break out of callus tissues on roots and spread rapidly when trees are severely stressed or when they are cut.

Armillaria root disease centers develop when neighboring trees are infected and killed over many years. Expansion rates probably average 1 foot per year, but may be 2 to 3 feet in some stands. Disease centers often contain infected old-growth stumps, the original source of infection, and trees in several stages of deterioration. Fortunately, some disease centers become inactive and damage subsides.

In addition to tree mortality, Armillaria root disease can cause butt rot and reduction of growth. If a tree is not directly killed, a compartmentalized root and butt rot may occur, especially in nonresinous conifers such as hemlock and true firs. The amount of bark killing and associated internal decay are dependent on inoculum potential, tree vigor, tree age, tree species, and host genetics.

Management

Effective and practical treatments to minimize damage are based on increasing host vigor, favoring disease-tolerant species, or minimizing inoculum.

The following recommendations for plantation establishment in areas affected by Armillaria root disease are based on reducing seedling and sapling infection by maintaining vigorous growth and choosing disease-tolerant tree species: (1) Use seed sources adapted to the area; Armillaria root disease has a history of killing offsite and exotic trees. (2) Use natural or artificial seeding of preferred tree species to supplement planting. Planted trees tend to be more susceptible to damage than those developing from seeds that germinate on the site. (3) Minimize practices that can lead to poor root development. (4) Plant or favor natural regeneration of species that showed tolerance to Armillaria root disease in the previous stand.

Treatments in stands of sapling-sized trees are designed to improve tree vigor and favor disease-tolerant species. The following sequence of activities is recommended: (1) Examine stands when their average age is 10 to 15 years, the time when symptoms of Armillaria root disease begin to appear. (2) Map concentrations of diseased trees and stumps and record data in a permanent file. (3) Thin infected stands having excessive stocking. Spacing should be wide enough to insure good response of released trees. Some additional killing of trees already infected may happen; however, most of the thinned trees will become less susceptible to damage. Precommercial thinning of ponderosa pine has been shown to decrease crop tree mortality caused by Armillaria root disease. In mixed-conifer stands, thinning should favor disease-tolerant species.

In eastern Oregon and Washington, treatments for stands of pole-sized and small sawtimber trees affected with Armillaria root disease should be designed to enhance tree vigor and minimize inoculum production. Special treatments are seldom needed in stands of trees this size in western Oregon and Washington because, in this area, the disease usually affects only smaller trees. The following management activities are suggested: (1) Map locations of disease centers and store the information in a permanent file. (2) Thin the healthy parts of a stand as normally prescribed. (3) Do not leave crop trees of susceptible species within 25 feet of killed trees. (4) Favor as crop trees species not suffering serious damage. (5) Patch cut severely diseased portions of stands where enough crop trees are not present for an adequately stocked stand and reforest with a more disease-tolerant species. (6) Avoid frequent salvage cuts in stands affected by Armillaria root disease because the harvesting creates more inoculum for infection of crop trees. Salvage cuts should remove all living symptomatic trees, as well as dead trees, so that entries do not have to be made more than once every 10 years.

Treatments for stands of large sawtimber in eastern Oregon and Washington should be designed to achieve inoculum reduction and regeneration of disease-tolerant trees. The locations of disease centers should be mapped before timber harvesting. It is easier to locate infected trees at this time than after stands have been harvested, as Armillaria root disease rarely causes stain or decay that can be seen on the surfaces of freshly cut stumps. Infected trees should have an identifying mark low on the root collar so that they will be visible after logging and slash burning.

If affected stands are to be clearcut, excavation of infected stumps should be considered where terrain, soil type, and economics permit. Uprooted stumps need not be burned to destroy fungal inoculum because air drying of stumps is sufficient to kill the fungus. Also, broken, infected root material that remains buried will decay and be of little consequence in future infection. In sites where stump excavation is not possible, reforestation should be done with species that are disease tolerant. If stands are to receive shelterwood or seed tree harvests, species tolerant of Armillaria root disease should be retained wherever possible; otherwise, the sites should be underplanted with species that are disease tolerant.

Trees with Armillaria root disease pose hazards to permanent structures, personal property, and people because they are prone to windthrow. Forest pathologists should be consulted

Figure 1. Pine engraver-killed trees. Root diseases are unlikely to be the cause of tree killing if all trees in a group are in the same stage of deterioration.

Figure 2. Laminated root rot. Root diseases are the likely causes when symptoms of affected trees range from dying to dead for several years.

Figure 3. Armillaria root disease. Declining, dying, and dead trees in a group are indicative of slowly spreading root diseases.

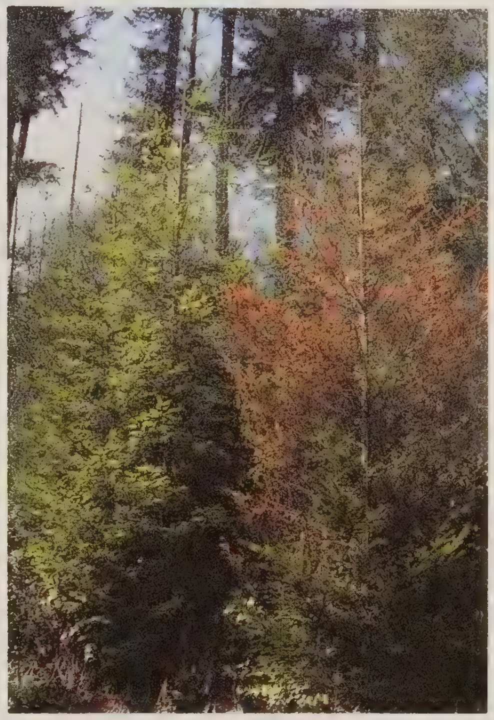

Figure 4. Laminated root rot. yellowing and loss of needles are crown symptoms of root diseases.

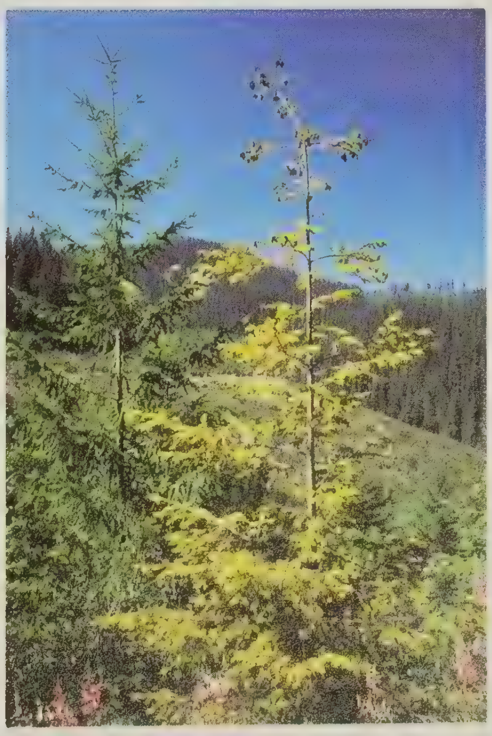

Figure 5. Distress cones on Douglas-fir being killed by black stain root disease.

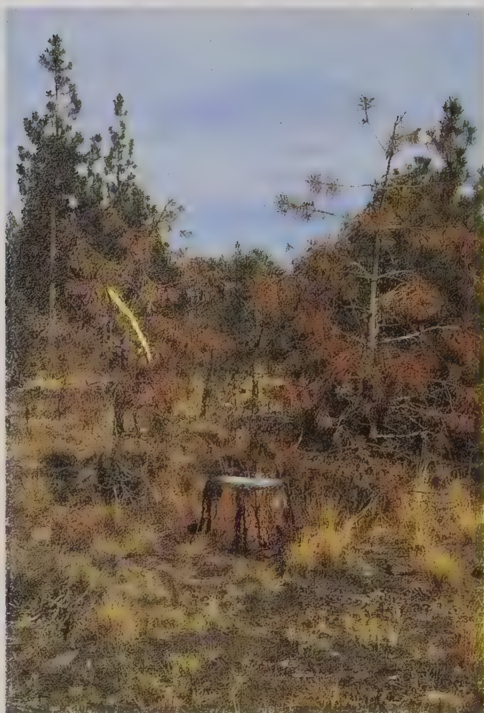

Figure 6. Annosus root disease. Root diseases of seedlings and saplings are often associated with large stumps from the previous stand.

Figure 9. Black stain root disease produces black to dark-brown stain in the outer sapwood of roots and lower stems.

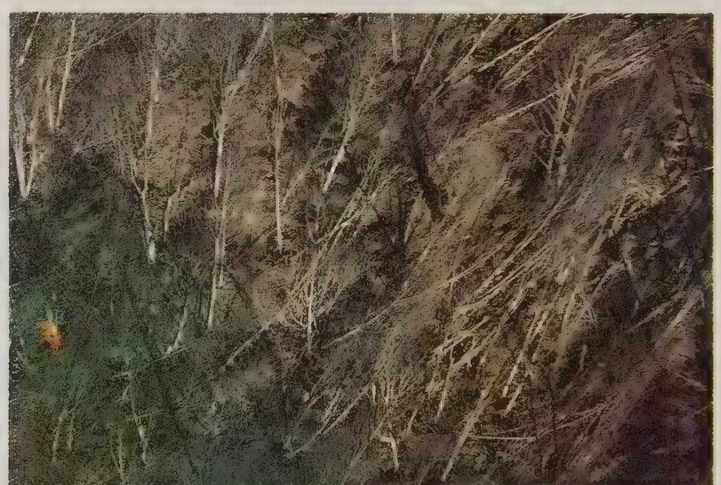

Figure 7. Trees without root diseases that are blown over by high winds are usually oriented in the same direction and have attached roots.

Figure 8. Port-Orford-cedar root disease can be recognized by dry, cinnamon-brown cambium and inner bark tissues abutting creamy, moist tissues.

Figure 10. Large animals, such as bears and porcupines, remove large patches of bark. Teeth and claw marks can be seen on the wood.

Figure 11. Sapsuckers make roughly parallel rows of holes on tree boles.

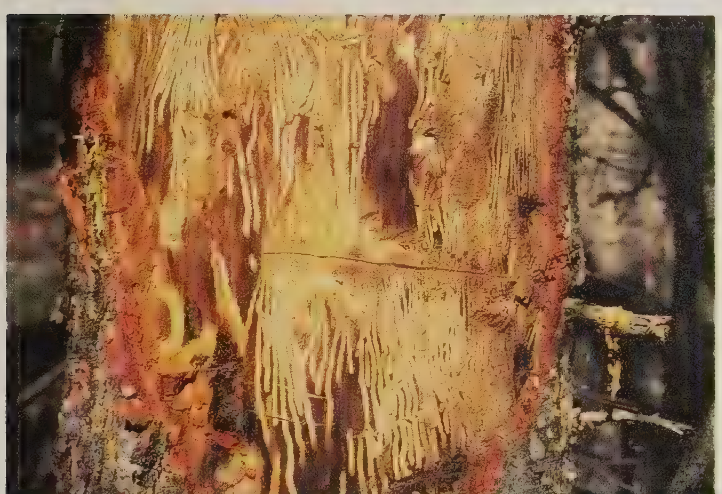

Figure 12. Bark beetles make galleries of distinctive patterns under the bark on many trees affected by root diseases.

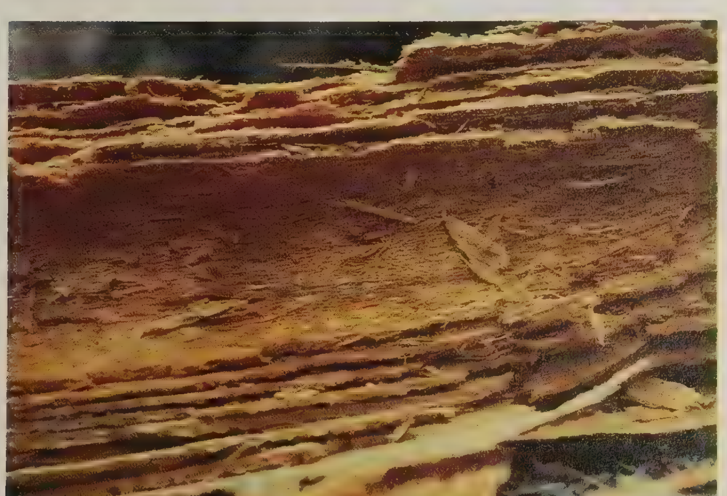

Figure 13. Laminated root rot causes affected wood to delaminate at the annual rings. Delaminated sheets are pitted on both sides.

Figure 14. Wood affected by *Phellinus weirii* contains reddish, whiskery, setal hyphae between delaminated sheets.

Figure 15. Laminated root rot incipient decay appears as reddish-brown stain at the edge of heartwood.

Figure 16. Ectotrophic mycelium of *Phellinus weirii* grows on the outside of affected roots.

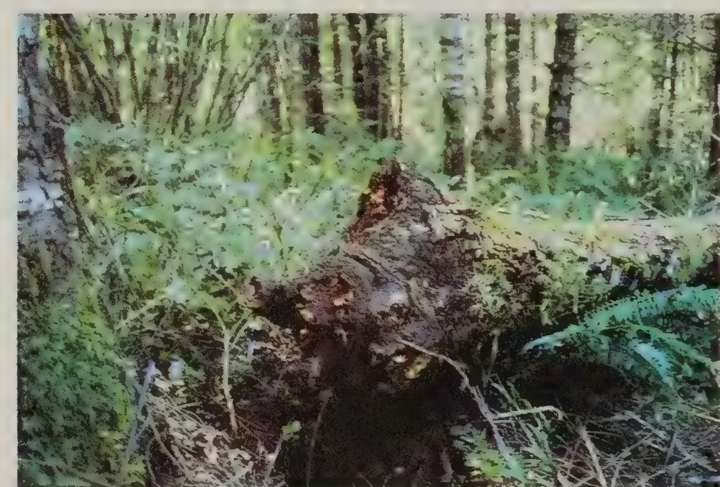

Figure 17. Root balls are formed when *Phellinus weirii* decays all the roots at the root collar and the tree topples.

Figure 18. Wood decayed by annosus root and butt disease may delaminate and have pits on one side of the sheet.

Figure 19. Annosus root disease may form reddish stain ahead of decay in roots and lower boles.

Figure 20. Small, leathery *Fomes annosus* conks are found at the root collar under the litter on ponderosa pine.

Figure 21. *Fomes annosus* conks are produced inside large, old stumps.

Figure 22. Cream-colored pustules of *Fomes annosus* are formed on the surface of infected roots.

Figure 23. The asexual stage of *Fomes annosus* appears as patches of white mycelium on disks incubated in warm, moist condition.

Figure 24. Armillaria root disease causes trees to produce copious resin flow at the root collar.

Figure 25. Brown leachate at the base of trees is a symptom of Armillaria root disease.

Figure 26. Advanced wood decay caused by *Armillaria obscura* is yellow, spongy, and contains black zone lines.

Figure 27. Armillaria root disease incipient decay is yellow-brown to red stain with a water-soaked appearance.

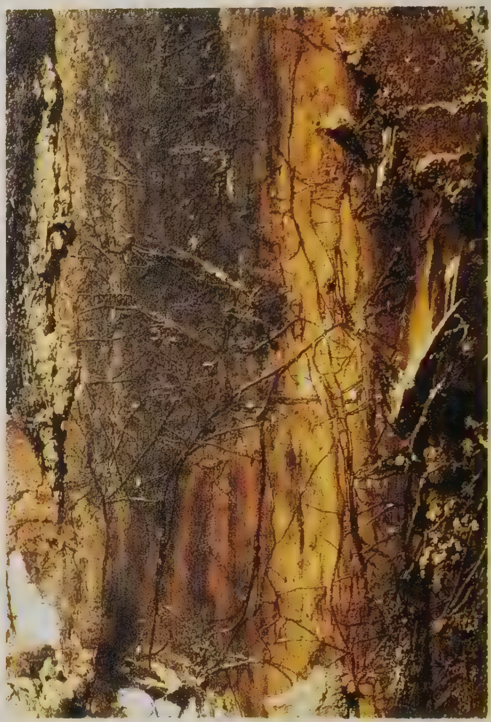

Figure 29. *Armillaria obscura* forms red-brown to black, string-like cords (rhizomorphs) under the bark of dead trees.

Figure 28. *Armillaria obscura* forms thick, white, mycelial sheets under the bark.

Figure 30. In the fall, *Armillaria obscura* produces golden-brown mushrooms at the base of dead trees and stumps.

Figure 31. *Fomes annosus* advanced decay is white, spongy, and contains black specks.

Figure 32. Fresh fruiting body of *Phaeolus schweinitzii*.

Figure 33. Roots infected by *Phaeolus schweinitzii* have red stain in the center.

Figure 34. Fruiting bodies of *Inonotus tomentus*—Left top, right underside.

Figure 35. Fruiting body of *Perreniporia subacida*, cause of yellow root rot.

when Armillaria root disease is suspected in developed recreation sites and before new developments are planned. Treatment recommendations can be made only after a thorough evaluation of the site. New developments should not be designed until pathologists have examined the sites for root diseases.

Additional Reading

Armillaria Root Disease of Conifers

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Annosus Root Disease

Annosus root disease, caused by *Fomes annosus*, occurs throughout the Pacific Northwest. Estimates of losses caused by this disease have not been made for Oregon and Washington, but it is believed to be the third most damaging root disease in the two States after laminated root rot and Armillaria root disease. Losses due to annosus root disease are known to be increasing.

Hosts

All conifers can be infected by *F. annosus*, but there are differences among species in degree of susceptibility and damage. In the Pacific Northwest, western hemlock, mountain hemlock, grand fir, white fir, and Pacific silver fir are highly susceptible to infection and can be severely damaged; ponderosa pine, lodgepole pine, noble fir, subalpine fir, and California red fir are moderately susceptible and sometimes damaged; and Douglas-fir, western redcedar, incense cedar, Port-Orford-cedar, western larch, western white pine, sugar pine, Engelmann spruce, and Sitka spruce are slightly susceptible and rarely damaged. Hardwoods are not damaged in the Pacific Northwest. There are apparently different strains of *F. annosus* that have rather specific host preferences. There is strong evidence, for example, that the fungus will not spread from white fir stumps to ponderosa pine and vice versa.

Recognition

Annosus root disease is more difficult to identify than are other common root diseases. Many infected trees do not exhibit aboveground symptoms. Trees that do, have symptoms similar to those produced by other root diseases, including chlorotic and thinning foliage, reduced height and lateral growth and, frequently, production of distress cone crops. Occasionally, infected trees will have some resin flow around the root collar. Crown symptoms are more commonly seen in resinous species, such as pines, than in nonresinous species. Western hemlocks, infected by *F. annosus*, seldom display crown symptoms even when their roots and stems are extensively colonized. True firs often display typical root disease symptoms; however, it is not uncommon for them to have extensive decay and yet show no external indication.

The most reliable way to diagnose annosus root disease is to find conks of the fungus. Conks are found mostly on trees in advanced stages of decline, on dead trees, and inside stumps. In dry localities, small (0.5-inch or less in diameter), buff-colored, leathery conks of *F. annosus* may be found in the duff layer on the exterior of roots and root collars of infected trees. Larger conks can be found in the decayed interior of old stubs and stumps and on the underside of exposed roots of infected, windthrown trees. They are usually shelf-shaped and often attain widths of 6 inches or more. The dark upper surface is concentrically furrowed, and the lower surface, which has

tiny pores, is creamy white with a narrow margin without pores around the outer edge. Conks are perennial and may have more than one tube layer.

Incipient decay caused by *F. annosus* appears as a reddish-brown stain with an irregular margin in the interior of butts and roots. In pines and true firs, decayed wood will often separate on the annual rings, and small pits (1 by 2 mm) may be present on one side of delaminated sheets. In other hosts and occasionally in pines and true firs, advanced decay is stringy with large, white streaks. Black flecks are usually scattered throughout decayed wood.

Disease Spread

Fomes annosus infects its hosts in two ways: by windblown spores being deposited and germinating on freshly exposed wood, and by mycelial growth from diseased roots to healthy roots via contacts. Infection by airborne spores occurs soon after woody tissue is first exposed. Wood that has been exposed to air for more than a month probably is no longer susceptible to infection, unless it has been frozen.

Infection of freshly cut stumps by *F. annosus* spores is the major way that new disease foci develop. Mycelia from germinating spores grow into the stumps, and after colonizing them, spread out through the roots. The fungus can spread to other trees when susceptible, healthy roots contact infected roots. The mycelium must grow in or on roots; it cannot grow through soil. The average rate of annosus root disease spread from colonized stumps is about 1.5 feet per year. On the west side of the Cascade Range, stump infection can occur at any time of year. Most infection east of the Cascades takes place in spring and autumn.

Size of stumps infected by *F. annosus* has an important influence on the potential for infection of adjacent trees. *F. annosus* can survive 40 years or longer in large, resinous stumps and roots. Survival time is shorter in small stumps and in nonresinous trees. Small stumps, created by precommercial thinning, may become colonized, but the fungus usually dies out within a few years. Small infested stumps are not a serious threat to remaining trees more than 3 feet away. Most annosus disease centers develop around large stumps created by commercial harvests. In eastern Oregon white fir and ponderosa pine stands, stumps less than 18 inches in diameter seldom act as infection foci.

F. annosus can infect the wood exposed when living trees are wounded. The rate of spread within living stems is two to three times greater upward than downward. One study of western hemlock found that 75 percent of the wounds over 1 square foot in size became infected by *F. annosus*.

Potential for stand damage by *F. annosus* increases with commercial thinning or partial cutting because of the creation of numerous stump and wound infection courts. Infection and damage are likely to be more severe in stands with multiple entries than in those with single entries. Generally, not all stumps will become infected after the first thinning because inoculum, in the form of spores, will be sparse unless the stand is close to other infested stands. The fungus will form conks in some infected stumps, so more inoculum will be available for infection at the next stand entry. Careless harvesting that results in many wounded trees also will cause increases in damage from annosus root disease.

Damage

F. annosus causes two kinds of damage, tree mortality and wood loss through decay. Tree death is the usual result of infection in resinous hosts and in white fir and grand fir in southeastern Oregon. Trees killed by annosus root disease tend to die standing rather than be windthrown. Mountain pine beetles *(Dendroctonus ponderosae)* and western pine beetles *(D. brevicomis)* often attack infected pines, and attacks by fir engraver *(Scolytus ventralis)* are common on infected true firs. Armillaria root disease is also frequently found on trees infected by *F. annosus*.

Hemlocks are much more likely to suffer butt decay than to be killed by *F. annosus*. Most decay will be associated with wounds and will be confined to woody tissues present when the trees were wounded. Losses due to annosus butt decay in hemlock stands tend to be small unless trees are older than 120 years or have been badly wounded.

Management

Management strategies to reduce losses caused by annosus root disease are dependent on the host species affected.

The following recommendations are offered for foresters who manage western hemlock stands: (1) manage hemlock stands in rotations of 40 to 120 years; damage caused by *F. annosus* increases rapidly in stands more than 120 years old, but is minimal in younger stands, (2) minimize wounding trees during thinning, (3) remove wounded trees because decay is more severe in them than in uninjured trees, (4) do not delay thinnings in overstocked hemlock stands because the volume gains from thinning greatly offsets losses from annosus root disease and, (5) retain other tree species such as Douglas-fir and western redcedar to maintain mixed-species stands.

Treatment of stump surfaces with borax is effective in preventing colonization of stumps by *F. annosus*, but is not practical in hemlock stands managed for timber production. Most hemlock stands are already infected, and damage is not serious enough to warrant the expense of borax treatments, particularly if other mitigating measures are used.

Damage can be reduced in true fir stands by treating stumps, by growing trees in rotations less than 120 years, by minimizing wounding, and by enhancing species mixes. *F. annosus* infection can be prevented by treating freshly cut stump surfaces with borax. A complete coating of dry borax, about one-eighth inch thick, applied to stump tops within 2 days after trees are cut is effective in preventing colonization. Salvage logging should be minimized in true fir stands affected by annosus root disease because frequent entries accelerate damage. True fir stands with severe damage from annosus root disease should be converted to other species. In some cases, stump removal may be an economically acceptable method of reducing inoculum so that true firs can be grown on the site. True firs should not be regenerated on sites having large amounts of well-distributed inoculum.

Ponderosa pine has not been seriously affected by *F. annosus* in Oregon and Washington, except in a few locations. Special measures to prevent damage are needed only in stands within 1 mile of severely affected pine stands. Borax treatment of pine stumps will prevent infection. Other species should be favored to create stands of mixed species if there are already many large infected stumps.

Whenever conifers are cut in campgrounds and other high-use sites, the stumps should be treated with borax to prevent infection by *F. annosus*. Trees in recreation sites known to be affected by annosus root disease should be carefully examined and removed if roots or stems are extensively decayed.

Additional Reading

Annosus Root Disease

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Black Stain Root Disease

Black stain root disease, caused by the fungus, *Ceratocystis wageneri*, was largely unrecognized in the Pacific Northwest prior to 1969. Since then, however, the disease has been detected in many areas, occasionally causing locally severe damage, and it appears to be increasing. Though black stain can be found in most parts of Oregon and Washington, it is far more common west of the crest of the Cascade Range than to the east; it tends to be most widely distributed and most damaging in southwest Oregon.

Black stain is a vascular wilt-type disease rather than a root rot. Hyphae of *C. wageneri* grow through host tracheids, block them, and interfere with water uptake and movement. Infected trees experience severe moisture stress, decline rapidly, and die. Often, disease-weakened trees are infested by bark beetles and woodborers.

Recognition

Black stain causes crown symptoms similar to those of other conifer root diseases, including sudden reduction of terminal growth, partial loss of older needles, foliage chlorosis, and production of distress cone crops. Diagnostic evidence of the disease is a dark-brown to purple-black stain in the sapwood of the lower stems and roots of infected trees. This stain often will not be visible in the outermost ring of xylem but will be apparent in the older sapwood. The only way to detect it in these cases is to chop into the older wood. In cross section, the *C. wageneri*-caused stain is usually limited to one or two growth rings and, unlike other stains introduced into tree stems by insects, rarely extends radially into the wood. It is typical for trees showing crown symptoms to have stain confined to a portion of the butt rather than encompassing the entire circumference.

Hosts

Douglas-fir is by far the most common host of black stain in the Pacific Northwest. Other less frequently encountered hosts include western hemlock, mountain hemlock, lodgepole pine, and ponderosa pine. There are several strains of *C. wageneri* one of which normally infects Douglas-fir and another the hemlocks and pines. The strains do not appear to cross from one host group to the other in nature. When Douglas-fir is the host, centers of black stain root disease usually are found in 15- to 25-year-old plantations or in heavily stocked patches of natural regeneration. It is believed that Douglas-fir over 30 years old develop substantial resistance to the disease. With other hosts, the disease affects trees of all ages in relatively pure stands.

Black stain centers typically appear as groups of dead and symptomatic trees with a few unaffected individuals intermixed. Most centers are small (0.1-acre or less), but some may occasionally be up to 10 acres. Groups of closely associated disease

centers within the same stand are common. Centers are encountered most frequently in areas where site disturbance has occurred or where many trees have been injured. Centers are especially likely to be concentrated along roads or on sites with a history of tractor logging and resultant soil compaction.

Disease Spread

Long distance spread of the black stain fungus involves insect vectors, predominantly root-feeding bark beetles (*Hylastes* sp.) and weevils (*Steremnius* sp. and *Pissodes* sp.). The microscopic fruiting bodies of *C. wageneri* form in the galleries of these insects, and the sticky spores that are produced adhere to the insects and are dispersed by them. The spore-carrying bark beetles and weevils feed and breed in roots of low-vigor trees, so occurrence of black stain root disease centers in disturbed areas probably reflects vector preference for stressed or injured hosts. Precommercial thinning may favor black stain establishment because *Hylastes* sp. are attracted to the stumps that are created.

Once insects have introduced *C. wageneri* into a tree, the pathogen spreads to new hosts via root grafts and contacts or by growing a short distance through the soil. Infection at this stage occurs regardless of host vigor. Rate of spread is much more rapid than that of most other root diseases. Average annual rate of radial enlargement was 4.8 feet in a sample of active disease centers monitored in Oregon.

C. wageneri appears to be relatively nonpersistent. The fungus does not live long after its host dies. If an infection center is to remain active, it is therefore necessary that there be a continuous network of living host roots for the fungus to infect as previously colonized trees die.

Management

Strategies for limiting losses due to black stain root disease involve both treating infested areas and preventing the formation of new disease centers on previously unaffected sites.

In already infected stands, nonhost tree species should be favored in thinnings or interplanted in disease centers. Thinnings in affected stands that lack good stocking of nonhosts should not be done unless overstocking is causing unacceptably slow growth and then should be done only in the period from June 1 to September 1.

Potential for establishment of new black stain centers can be reduced by minimizing site disturbance, tree injury, and insect vector attraction. In high-risk areas (within 1 mile of known centers of black stain disease), recommendations include: (1) Design harvest systems for minimum site disturbance, especially soil compaction. High-lead or skyline logging is preferable to tractor logging. If tractor logging must be done, it should be completed during the dry season, and areas involved in skid trails and landings should be kept to a minimum. Skid trails should be regenerated with nonhost tree species. (2) Avoid creating flooded or poorly drained areas in plantations or established stands of hosts during road building and maintenance. (3) Do not create patches of wounded or stressed hosts by pushing new roads through established stands. Do not use rotary blade brush cutters to clear roadsides. Do not drop cable lines into stands when harvesting adjacent units. (4) Minimize insect vector attraction by scheduling precommercial thinnings in Douglas-fir plantations between June 1 and September 1, if possible. (5) Favor as crop trees tree species that are not susceptible to black stain root disease. In areas of lower risk, care should be taken to avoid excessive soil compaction and tree damage during timber harvesting and road construction.

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Port-Orford-Cedar Root Disease

Port-Orford-cedar root disease, caused by the fungus *Phytophthora lateralis*, has been killing Port-Orford-cedar, its only host in the Pacific Northwest, for more than 60 years. Although not all Port-Orford-cedar sites are infested, root disease can be found throughout most of the host range in Oregon.

Recognition

The first external evidence of the disease is a slight discoloration of the foliage which, within a few weeks to months, depending on weather conditions and tree size, gradually takes on a yellow, wilted appearance. Progressive color changes occur—from yellow to bright red, then red-brown, and finally brown. Trees usually lose all foliage 2 to 3 years after death. In areas where the disease has been active for several years, dead and dying trees with all degrees of foliage symptoms are visible.

Port-Orford-cedar root disease is best identified by the cinnamon-colored inner bark and cambium that abruptly joins creamy white, healthy inner bark in roots and lower boles. Just prior to tree death, the discolored zone may extend 2 to 5 feet aboveground. This symptom is most readily seen on trees that are wilted or yellow. In trees that have been dead for several months, all the inner bark tissues are brown, dry, and often full of galleries made by cedar bark beetles.

Disease Spread

Man has been the major vector of *P. lateralis*. The disease is spread by moving infected seedlings and infested soil into disease-free sites. Livestock and wildlife can move the fungus if infested soil sticks to their feet; however, this spread is minor compared to that caused by man.

Infection of cedar occurs through uninjured root tips and involves specialized spores called zoospores. These delicate spores can swim short distances in water. They are totally dependent on free water for infection and spread and cannot survive in dry soil. Spread of zoospores is virtually all downslope or downstream in water moved by gravity. Root tips release chemicals that attract zoospores and stimulate their germination. After the zoospores germinate, mycelium penetrates the roots, kills the phloem, and spreads internally to the base of the tree and to other roots. If roots of adjacent trees are grafted, the mycelium can grow from root to root.

Upslope movement of the disease is accomplished entirely by vectors or mycelial growth in the roots which averages about 6 inches per year in pure stands. In addition to the infective zoospores, the fungus produces durable resting spores able to withstand dry, warm soil. These durable spores are dispersed into the soil as the infected roots die and disintegrate and can survive in clods of soil moved by machinery and, to a lesser extent, by animals. With the onset of cool, wet weather, the durable spores germinate and produce zoospores to start the infection cycle anew.

Topography has a great influence upon disease spread because gravity carries the zoospore-infested water downslope. Steep slopes dissected by drainages quickly channel the infested water into streams, thereby restricting spread across the slopes. On broad slopes or flat areas with few streams, the zoospore-infested water can spread over a large area and result in infection of many trees. Concave sites with Port-Orford-cedar are vulnerable to infestation because they are easily flooded; convex slopes are less vulnerable because of channeling.

Management

Port-Orford-cedars that are genetically resistant to *P. lateralis* have not yet been found.

Fungicides are available for preventing infections of host plants by members of the genus *Phytophthora*, and one, metalaxyl, would probably be effective in preventing Port-Orford-cedar root disease. It could be used to protect valuable ornamental Port-Orford-cedar, but its use in forest stands is seen as impractical.

At the present time, the only known way of eliminating *P. lateralis* from an infested area is total removal of the host for several years. The exact length of time is not known but is at least 3 years, and more likely 5 years.

Management of Port-Orford-cedar root disease has to be based upon excluding the pathogen from cedar-growing sites. Once *P. lateralis* infects its host, death of the host and spread downslope is highly probable. In forests where growing of Port-Orford-cedar is a management goal, areas capable of supporting economically viable quantities of cedar that can be protected from disease introductions should be designated as cedar production sites. Cedar production sites would have the following characteristics: (1) the sites should have no cedar root disease present; (2) the sites should not be located below infested roads nor be bisected by roads; and (3) the sites should not be exposed to infested runoff water.

Port-Orford-cedar production sites should be mapped and forest users made aware of their locations to avoid introduction of disease. Actions that would threaten the disease-free status of the sites should be avoided as long as cedar production is a goal. Livestock should not be allowed to graze in cedar production areas. The only occasions when ground-based harvesting equipment, such as bulldozers, skidders, and other devices capable of moving soil, would enter cedar production sites would be during timber harvesting or for fire suppression. Equipment with soil on it should be cleaned with high-pressure water hoses or steam before it could enter a cedar production area. Logging systems should be designed that involve a minimum amount of road building and ground lead yarding.

Even if all these restrictions are followed, it is possible that some cedar production sites will become infested. To avoid severe losses, Port-Orford-cedar should not constitute more than one-third of the total stocking even in the designated cedar production sites.

Port-Orford-cedar can be grown in areas that do not meet the criteria for cedar production sites. Disease introductions should be viewed as highly probable occurrences in these areas, but damage can be held to tolerable levels. Cedar should be spaced at least 25 feet apart or grown in widely separated clumps to avoid tree-to-tree disease spread. Other tree species should be favored within a 50-foot-wide band below roads and 30 feet on each side of drainages that could carry infested water. Cedar should be concentrated on convex slopes where it will not be exposed to infested runoff. Full stocking should be maintained with other tree species, such as Douglas-fir and hemlock, with Port-Orford-cedar retained as an excess because it will grow in the shade of the other species. Cedar should not comprise more than 20 percent of the desired stocking. Ground-based harvesting equipment should be cleaned with water or steam to remove soil containing spores before being used in disease-free stands, even if those stands are not Port-Orford-cedar production sites.

If sites not in production areas are infested, all merchantable dead, dying, and healthy-appearing trees in vulnerable microsites should be salvaged with one entry. Repeated salvage entries into the same site should be avoided because this action increases the probability of spread to other sites. Other tree species should be favored during thinning and regeneration. Cedar should be restricted to convex slopes that do not receive infested drainage water. This can be accomplished during thinning. Soil and debris should not be moved to uninfested sites.

Additional Reading

Port-Orford-Cedar Root Disease

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Other Forest Root Disease

There are other forest root diseases in the Pacific Northwest that, although not important on a regional scale, do cause substantial damage in some stands. Three of these less important root diseases are described in this section.

Schweinitzii Root and Butt Rot

Schweinitzii root and butt rot is caused by *Phaeolus schweinitzzi,* often called the velvet-top fungus. It is one of the most important butt and lower stem decays of old-growth trees, especially Douglas-fir. Occasionally, it acts as a killing root disease of small trees.

Phaeolus schweinitzii is found most frequently on Douglas-fir. Other hosts include pines, spruces, larch, and true firs.

Trees affected by Schweinitzii root and butt rot typically show no aboveground symptoms; crowns appear normal. The only reliable way to detect the disease on living trees without cutting into stems to expose the decayed wood is to find mushroomlike fruiting structures produced by the fungus. These emerge from the ground around the base of an infected tree in late summer and in autumn; less commonly, they emerge directly from the stem . At first, they are red-brown with a yellow velvet tinge, but after a few weeks, they turn dark brown and become punky. Nevertheless, they are still recognizable for up to a year after being formed. Fruiting bodies growing on the ground have a circular shape with a depressed center and taper to a short, thick stalk; those growing on trees usually have overlapping shelves (fig. 32). Diameters of the tops range from 3 to 16 inches across. The fruiting structures are produced only on trees with extensive advanced decay and may not be formed every year.

The interior of roots infected by *P. schweinitzii* is stained red (fig. 33). In Douglas-fir, swollen root stubs form when the fungus rots root ends. Red stain can be seen above advanced decay columns in the stems. Wood with advanced decay is brown, dry, and separates into cubes, often with thin, crust-like mycelial sheets in the shrinkage cracks.

Most infection apparently takes place through root tips rather than through basal fire scars as was once believed. After entering through root tips, the fungus becomes confined to root interiors and then may spread into stem interiors. Most tree-to-tree spread is by mycelia growing through soil litter, although a minor amount of tree-to-tree spread via root contacts does happen.

Extensive decay of tree butts is the most common form of damage. Wind breakage of decayed trees above the groundline is much more common than windthrow. Trees are seldom killed as a result of root decay alone. Trees with extensive decay may be preferentially attacked by bark beetles, and colonization of swollen root stubs by *Armillaria obscura* is also common.

Trees with evidence of Schweinitzii root and butt rot should be harvested or cut because decay volume becomes greater with time, and such trees are likely to break. This characteristic makes infected trees especially dangerous in recreational sites. Older trees should be carefully inspected. Planting susceptible tree species on sites that had severely infected trees should not lead to serious damage unless the trees are grown for more than 150 years. Schweinitzii root and butt rot generally is not a problem in younger stands.

Tomentosus Root Rot

Tomentosus root rot, caused by *Inonotus tomentosus,* is another root disease that occasionally damages Pacific Northwest conifers. It is not thought to be widespread.

Engelmann spruce is the most common host of *I. tomentosus* in Oregon and Washington. The fungus was responsible for nearly 44 percent of all infections and about 10 percent of the decay volume in a study of Engelmann spruce in the Blue Mountains (northeastern Oregon). It is seen infrequently on true firs, lodgepole pine, ponderosa pine, and Douglas-fir. Trees affected by this disease may be as young as 20 years, but it is most commonly seen in stands more than 40 years old.

Trees with most of their roots decayed by *I. tomentosus* have crown symptoms similar to those caused by other root diseases, so crown symptoms alone cannot be used to identify tomentosus root rot. Wood in early stages of decay is stained reddish brown. Advanced stages of decay contain many small white pockets separated by wood stained red to brown.

The best way to identify the disease in forests is to find the mushroom-shaped fruiting bodies. *I. tomentosus* forms small (1- to 2.5-inch diameter) yellow to rusty brown fruiting bodies. The upper surface is distinctly velvety to hairy; the undersurface is a white to light brown tube layer (fig. 34). Fruiting bodies with mycelium attached to roots may emerge from the soil. These have a thick central stalk. Shelflike fruiting bodies may form on the root collars and butts of infected trees. Fruiting bodies usually are produced only during wet, late summers and in early autumn. Although they are fleshy, they will remain recognizable for several months.

Most infection by *I. tomentosus* takes place in roots and is usually a result of mycelium growing from an infected root to a healthy root across a contact. Spores can infect roots, particularly those with wounds that expose the cambium or xylem, but this is thought to account for a minor amount of infection. The fungus can enter trees through dead roots, such as might result from poor planting. Spread rate is slow, probably averaging about 5 inches or less per year. The fungus can persist in large, dead roots for at least 20 years. Tomentosus root rot slowly kills infected trees by decaying the roots. Trees usually will not die until they have been infected for 15 to 20 years. Windthrow may take place. Butt decay may extend 3 to 6 feet up the tree.

In stands damaged by tomentosus root rot, less susceptible tree species should be favored during thinning and planting. Cutting boundaries should extend at least 50 feet beyond symptomatic trees. Engelmann spruce, in particular, should not be planted within 50 feet of diseased sites. Care should be taken to avoid damaging roots of susceptible species if they are to be planted in or near diseased areas.

Trees with tomentosus root rot should be removed from recreation areas and other sites with valuable targets because they are prone to windthrow.

Yellow Root Rot

Perreniporia subacida, the white-root conk, causes yellow root rot of several conifer species in Oregon and Washington. It is usually found on suppressed or very weakened trees. It is rarely seen in vigorous trees.

Hosts of *P. subacida* include Douglas-fir, western hemlock, mountain hemlock, lodgepole pine, larch, grand fir, and western redcedar.

The only reliable way to identify yellow root rot in the forest is to find the conks. The appressed conks are white when fresh and become cream to dirty yellow-orange as they age (fig. 35). They may be up to ½-inch thick. Size can vary from a few inches to 2 or 3 feet long. They are found on the underside of root crotches or exposed roots and under fallen trees.

Advanced stages of wood decay have irregularly shaped pockets in the spring wood that run together, forming masses of stringy fibers. The annual rings of wood decayed by yellow root rot separate easily and may be confused with laminated root rot; however, *P. subacida* does not produce either red-brown setal hyphae or small pits in the layers of decayed wood. Small black flecks may appear in the pockets or masses of fibers.

Most infection by *P. subacida* probably results from contact by colonized roots with susceptible roots. The role of spores in initiating new infections is not known. Tree roots that are severely stressed appear to be most susceptible to infection and decay.

Killing of stressed trees is the most obvious form of damage caused by *P. subacida* . Minor amounts of butt rot occasionally result.

Damage caused by *P. subacida* is not serious enough in the Pacific Northwest for treatment techniques to have been developed. Trees affected by this disease should be removed during harvesting operations, and it may be advisable to favor tree species not showing damage when thinning or planting sites affected by *P. subacida* .

Root Pathogen Complexes and Bark Beetle-rot Pathogen Interactions

Incidents of two or more pathogens causing damage in a single location and in a single tree occur frequently in Pacific Northwest forests. The following complexes have been observed to cause damage in several locations:

Pathogens	Species Affected
Phellinus weirii and *Armillaria obscura*	Douglas-fir, western larch, white fir, grand fir, noble fir
Phellinus weirii and *Fomes annosus*	White fir, grand fir
Phellinus weirii and *Ceratocystis wageneri*	Douglas-fir, Mountain hemlock
Armillaria obscura and *Fomes annosus*	Western hemlock, white fir, grand fir, ponderosa pine
Armillaria obscura and *Ceratocystis wageneri*	Douglas-fir, ponderosa pine
Phellinus weirii, *Armillaria obscura*, and *Ceratocystis wageneri*	Douglas-fir
Phellinus weirii, *Armillaria obscura*, and *Fomes annosus*	Douglas-fir, grand fir, and ponderosa pine
Armillaria obscura and *Phaeolus schweinitzii*	Douglas-fir

Little is known about the biology of root disease complexes, especially regarding infection, disease spread and intensity, and pathogen survival. Recognition of root pathogen complexes requires detailed examination of infested sites because presence of one or more pathogens may be obscured by others. Where two or more pathogens are causing damage on a site, management of one disease will not necessarily minimize or prevent damage caused by other diseases present. For example, areas damaged by *Phellinus weirii* and planted with species tolerant to it may be damaged by *A. obscura* if significant amounts of *A. obscura*-infested root material are left from the previous stand. Treating stumps with borax to prevent colonization by *F. annosus* will not prevent subsequent stand damage by *P. weirii* or *A. obscura* if they are also present in the stand.

Root diseases are particularly important as agents predisposing trees to bark beetle attack. When bark beetle populations are epidemic, trees of all vigor classes may be attacked. When beetle populations are at normal (endemic) levels, mostly weak and injured trees are infested. In some areas, 98 percent of the trees successfully attacked by bark beetles are infected by root pathogens. The following tabulation lists bark beetle-root pathogen associations in the Pacific Northwest:

Pathogen	Host	Bark beetle
Phellinus weirii	Douglas-fir	Douglas-fir pole beetle, Douglas-fir beetle, Douglas-fir engraver
Phellinus weirii	True firs	Fir engraver, western balsam bark beetle
Phellinus weirii	Western hemlock	Hemlock engraver
Armillaria obscura	Pines	Western pine beetle, mountain pine beetle, pine engraver
Armillaria obscura	Douglas-fir	Douglas-fir pole beetle, Douglas-fir engraver
Armillaria obscura	True firs	Fir engraver
Armillaria obscura	Western hemlock	Hemlock engraver
Ceratocystis wageneri	Douglas-fir	Douglas-fir beetle, Douglas-fir pole beetle, Douglas-fir engraver, *Hylastes nigrinus*, *Pissodes fasciatus*, *Steremnius carinatus*
Ceratocystis wageneri	Ponderosa pine	Mountain pine beetle, western pine beetle, turpentine beetle, *Hylastes macer*
Fomes annosus	True firs	Fir engraver
Phytophthora lateralis	Port-Orford-cedar	Cedar bark beetle

Foresters checking dead and dying trees should be aware of the close association between root diseases and bark beetles. The search for cause of death should not be terminated with discovery of bark beetle galleries. Roots should be checked also for evidence of disease. The best way to minimize damage supposedly caused by bark beetles may be, in many cases, to manage root diseases and other factors that weaken trees.

Additional Reading

Pest Complexes

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Root Disease Survey Methods

Surveys should be made in root-diseased stands where management activities are being considered to identify the causal fungi and affected hosts and to determine locations of infestation. This information is needed to develop treatment prescriptions. Root disease treatments can be costly, so it is important to identify carefully the diseased portions of stands.

In most instances, people trained in root disease identification can make accurate field diagnosis by looking at wood decay characteristics and at fungus structures, such as setal hyphae, conks, and mycelial fans. A pulaski for digging and chopping and a 10-power hand lens are the only items needed for field identification. Occasionally, samples will have to be collected for laboratory diagnosis by forest pathologists when field identifications cannot be made. If samples are to be sent somewhere for identification, the specimens should be large enough so they will not quickly dry out. Samples to be mailed should be wrapped in damp, but not dripping wet paper and enclosed in plastic bags.

Several methods can be used to survey forests for root diseases. Stand management objectives should dictate the survey technique selected. Root diseases are seldom uniformly distributed throughout affected stands. For this reason, we recommend that root disease surveys be designed to sample all portions of stands to maximize the probability of detecting most or all of the disease centers. Do not assume that one portion of a stand is representative of the entire stand. Routine silvicultural examinations that use only one line to bisect stands are likely to miss root disease centers. Systematic surveys that follow compass lines superimposed over the entire stand are preferrable to walk-through surveys that do not follow predetermined lines. However, walk-through surveys can be useful when time is especially limiting and the only information needed is the presence or absence of root diseases. It is much easier to draw maps of root disease-affected areas within stands from systematic surveys than it is from walk-through surveys.

Variable radius plots arranged in a grid pattern can be used to obtain measurements of stems, basal area, and volume per acre of diseased and healthy trees. Grid patterns of 2 by 3 chains are used commonly where it is important to have very accurate determinations of root disease locations. Patterns of 5 by 5 and 10 by 10 chains are used where time available for survey is limited or it is not as important to have highly accurate delineations of disease centers. Fixed-area circular plots can be used with variable plots to measure smaller diameter trees and seedlings not measured on variable plots.

Often, the area affected by root diseases may be the desired unit of measurement. Fixed-area circular plots arranged in a grid pattern or strip plots arranged across the stand can be used to measure the area infested. The proportion of circular plot or surveyed strip that is affected is measured and the value expanded to represent the entire area. Another method used to measure and map the area affected is the line-intercept survey. A series of survey lines are followed through the stand. The

length of line that falls within diseased areas, as defined by symptomatic trees divided by the total length of survey line, is the approximate proportion of affected area. The line-intercept method is much faster than either variable or fixed-area plot methods, especially in lightly or moderately affected areas.

Helicopter surveys can be used to estimate root disease damage in stands of young trees. Where recently killed or dying trees appear red or yellow and contrast sharply with healthy green trees, it is possible to make accurate counts of damage (trees per acre) from the air. This approach does not work well in dense stands of pole-sized or larger trees west of the Cascades. Helicopters are better than fixed-winged aircraft because they can fly slower and hover. A companion ground survey also must be made to determine causal agents of mortality.

Aerial photographs can be used to estimate the extent of tree killing caused by root pathogens. Large scale (1:4000, 1:6000, or 1:8000) color photographs are used most commonly. Dead, large diameter trees can be counted directly on photos. Diseased areas, as determined by the presence of dead and dying trees and by windthrow, can be delineated on aerial photos. Use of aerial photographs to measure root disease is more successful in stands east rather than west of the Cascades because the lower stocking allows better detection of windthrown trees. Low-level aerial photography is useful on the west side in plantations less than 20 years old, but it has not been a reliable method for detecting root diseases in pole-sized and larger diameter stands.

There are no easy methods for estimating damage caused by root diseases in forested areas. Soil is not transparent, and trees cannot tell us where they hurt, at least not until it is too late to protect them. Root disease surveys require more time than normal stand cruising procedures. More importantly, the key to making accurate estimations of damage lies in the surveyor's ability (1) to differentiate root diseases from agents causing similar symptoms and (2) to identify root pathogens causing the disease. Disease management for a particular area is dependent on the accuracy of the survey, and errors in identification of root diseases can lead to inappropriate treatments with ramifications far into the future. Root disease surveys should be performed by individuals who have had training and experience in disease identification.

Additional Reading

Survey Methods

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Williams, R. E., and C. D. Leaphart. A system using aerial photography to estimate area of root disease centers in forests. Canadian Journal of Forest Research. 8:214-219. 1978.

Safe Use of Pesticides

Pesticides used improperly can be injurious to people, animals, and plants. Follow the directions and heed all precautions on the labels. Store pesticides in original containers under lock and key —out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides where there is danger of drift when honeybees or other pollinators are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the label.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.